Evaluating the Performance of A Sponge-based Moving Bed Bioreactor on Micropollutants Removal

by

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CERTIFICATE OF ORIGINAL AUTHORSHIP

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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List of Abbreviations

CAS	Conventional activate sludge
DO	Dissolved oxygen
EPS	Extracellular polymeric substance
GAC	Granule activated carbon
GC-MS	Gas chromatography-mass spectrometry
HRT	Hydraulic retention time
MBBR	Moving bed biofilm reactor
MBR	Membrane bioreactor
MBBR-MBR	Moving bed biofilm reactor-membrane bioreactor
MF	Microfiltration
MLSS	Mixed liquor suspended solids
MLVSS	Mixed liquor volatile suspended solids
OLR	Organic loading rate
PAC	Powdered activated carbon
PCP	Personal care product
PPCP	Pharmaceutical and personal care product
PU	Polyurethane
PVA	Polyvinyl alcohol
PVDF	Polyvinylidene fluoride
SMP	Soluble microbial products
SND	Simultaneous nitrification–denitrification
SPE	Solid phase extraction
SRT	Sludge retention time
TMP	Transmembrane pressure
TN	Total nitrogen
TOC	Total organic carbon
WWTP	Wastewater treatment plant

List of Symbols

Cs, a	Concentration of micropollutant on the attached biosolids (μg/g)
Cs, s	Concentration of micropollutant on the suspended biosolids (μg/g)
$C_{w,\ eff}$	Average effluent concentrations of micropollutants (ng/L)
$C_{w,\ inf}$	Average influent concentrations of micropollutants (ng/L)
J	Permeation flux ($L/m^2 \cdot h$)
K_{OW}	Octanol–water partition coefficient
L_s	Load of micropollutant removed via sorption (ng)
L_b	Load of micropollutant removed via biodegradation (ng)
L_{inf}	the influent load of micropollutants over the experimental period (ng)
L_{eff}	the effluent load of micropollutants over the experimental period (ng)
MLSS	Mixed liquor suspended biosolids concentration (g/L)
pK_a	Acid dissociation constant
ΔP_T	Transmembrane pressure (kPa)
Q	Flow rate of the MBBR (L/day)
R_c	Cake resistance formed by cake layer deposited over membrane surface (m^{-1})
R_f	Fouling resistance caused by pore plugging and/or solute adsorption onto the membrane pore and surface (m^{-1})
R_m	Intrinsic membrane resistance caused by membrane itself and permanent resistance (m^{-1})
ΔSS	Increased amount of attached biosolids over the study period (g)
T	Duration of the study period (day)
μ	Viscosity of the permeate (m^2/s)

Abstract

The ubiquitous occurrence of micropollutants and their metabolites in the aquatic environment has posed threats to living organisms to a great extent. However, effective micropollutants removal normally requires longer hydraulic retention time (HRT) when using biological treatment systems. As an ideal and low-cost material for attached-growth microorganisms, polyurethane sponge has exhibited high potential to eliminate micropollutants. In this study, a sponge-based moving bed biofilm reactor (MBBR) was investigated at four different HRTs (24, 18, 12, 6 h), to better understanding of the effect of HRT on micropollutant removal. The MBBR as pretreatment to a membrane bioreactor (MBBR-MBR hybrid system) was also evaluated. Four groups of frequently detected micropollutants in wastewater (total 22 compounds) were selected, namely pharmaceuticals and personal care products (PPCPs), pesticides, hormones and industrial chemicals.

The MBBR alone showed stable and effective removals of TOC (92.6% - 95.8%), COD (93.0% - 96.1%) and NH_4-H (73.6%-95.6%) at all HRTs while improving PO_4-P removal at HRT of 18 h. The MBBR showed the highest performance efficiency for removing DOC, COD, NH_4-N, PO_4-P and TN at HRT of 18 h, which were 96.1±0.4%, 97.4±0.8%, 91.1±1.6%, 49.9±7.2%, and 72.3±6.9%, respectively. This could be explained by the food to microorganisms (F/M) ratio in the MBBR. In addition, higher NH_4-N removal at HRT of 18 h could be attributed to the increased population of ammonium oxidation bacteria in the MBBR unit. Moreover, the use of phosphate for biomass growth and the phosphorus uptake by phosphate accumulating organisms (PAOs) could contribute to the high removal of PO_4-P at HRT of 18 h. In terms of micropollutants removal, MBBR achieved comparable removal compared to other biological treatment such as activated sludge processes and membrane bioreactor. Although the micropollutants were subjected to biodegradation and sorption, the results indicated compound-specific variation in removal at all HRTs, ranging from 10.7% (carbamazepine) to 98.4% (ibuprofen). Among the selected micropollutants, most of them were biodegradable excluding carbamazepine, fenoprop and metronidazole. In addition, the micropollutants removal could remain constantly high even at lower HRTs with more consistent removal efficiency over the

experimental period (except for carbamazepine, fenoprop, 17α-ethinylestradiol and 4-tert-octylphenol). Particularly, at HRT of 18 h, the removal of diclofenac was significantly improved by more than 30% and the removals of ketoprofen, gemifibrozil, acetaminiphen, bisphenol A, and pentachlorophenol were also better. Overall, HRT of 18 h was the optimum HRT for biological degradation of the micropollutants in the MBBR.

When using an MBBR as pretreatment to an MBR, the MBBR-MBR hybrid system achieved better removal efficiencies for selected micropollutants, such as metronidazole and carbamazepine. Both metronidazole and carbamazepine are nitrogen bearing compounds, where nitrogen is bound to the cyclic structure. The infinite SRT applied in this study could have facilitated the enhanced removal of the nitrogenous compounds. Even MBR can prevent the washout of slow-growing microorganisms like nitrifiers, the impact of MBR removal was minimal at all HRTs. This may probably due to the low MLSS concentration and the large pore size (0.2 μm; two orders of magnitude larger than the molecular sizes of micropollutants) of the MF membrane used in this study. In addition, a longer HRT (e.g. HRT of 24 h or 18 h) can significantly mitigate membrane fouling when compared with a relatively short HRT (e.g. HRT of 6 h). Especially, the TMP value maintained less than 15 kPa for 60 days (HRT of 18 h) and 68 days (HRT of 24 h). The level of EPS were similar at the beginning of all HRTs, then gradually increased to 15.24 mg/L, 16.43 mg/L, 19.88 mg/L and 22.93 mg/L at the end of operation for MBBR unit under HRT of 24 h, 18 h, 12 h, and 6 h, respectively. The SMP concentration varied for different HRTs but showed minor variation under the same HRT. The SMP concentration was lower at HRT of 24 h, while a significantly higher SMP concentration was observed at HRT of 6 h. As a whole, the MBBR-MBR hybrid system showed improvement in both micropollutants elimination and mitigation in membrane fouling.